

**SUMMARY OF THE INVENTION**

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The present invention is a system that measures and displays information about the movement of an object, in particular a sports object such as a golf ball. In particular, the device measures the speed and direction of movement, as well as spin rate and spin axis orientation of the object.

A method and article of manufacture of the invention for determining a movement characteristic of an object includes reflecting electro-magnetic energy from a sensor off the object. The electro-magnetic energy reflected off the object at the sensor is then received and parameters of a model of the movement of the object determined based on the reflected electro-magnetic energy. Then a movement characteristic of the object based on the determined model parameters is determined.

The movement characteristic of the object that the method may determine include[s] the speed, distance, location, spin angle, or spin rate. In a preferred embodiment, electro-magnetic energy from three sensors may be reflected off the object and the electro-magnetic energy reflected off the object may be received at the three sensors. Further, each sensor's electro-magnetic energy transmission path may be non-parallel to the movement path of the object.

The sensor may be a Doppler radar sensor or a continuous wave Doppler radar sensor. In a further embodiment, the electro-magnetic energy from the sensors may be reflected off a contrast marker of the object and the electro-magnetic energy reflected off the contrast marker of the object may be received at the sensors. The contrast marker of the object may be highly reflective of the electro-magnetic energy generated by the sensors.

An apparatus of the invention for determining a movement characteristic may include an object having a movement path and an electro-magnetic sensor. The sensor generates electro-magnetic energy to be reflected off the object and receives the electro-magnetic energy reflected off the object. The apparatus also includes means for determining parameters of a model of the movement of the object based on the reflected electro-magnetic energy and means for determining a movement characteristic of the object based on the determined model parameters

The means for determining a movement characteristic may include[s] means for determining one of the speed, direction, location, spin angle, and spin rate of the object based on the determined model parameters. The apparatus may also include a second and a third electro-magnetic sensor.

02 The second sensor generates electro-magnetic energy to be reflected off the object and receives the electro-magnetic energy reflected off the object. The third sensor also generates electro-magnetic energy to be reflected off the object and receives the electro-magnetic energy reflected off the object. In the apparatus, the sensor's electro-magnetic energy transmission path may be non-parallel to the movement path of the object.

The sensor of the apparatus may be a Doppler radar sensor or a continuous wave Doppler radar sensor. Further, the object of the apparatus may include a contrast portion or contrast marker. In this apparatus, the sensor generates electro-magnetic energy to be reflected off the contrast marker of the object and receives the electro-magnetic energy reflected off the contrast marker of the object.



ABC. Given that the cosine function is defined as  $\cos A = \frac{b}{c}$  for a right triangle, accordingly, it

follows that  $s_t = \left| \frac{(t - T_R)S}{\sqrt{(t - T_R)^2 S^2 + R^2}} \right|$ .

The speed/distance model assumed a constant actual target speed  $S$ . The speed of the object is presumed to be constant or changing slowly and the observation time of the sensor of the object is short enough that a change in speed is not evident for the application shown in FIG 1 and FIG.

2. The speed/distance model can be modified to support varying speeds or velocities. For example, the speed/distance model may include another parameter such as constant acceleration, *i.e.*,  $s_t = F_t(S, A, R, T_R)$  where  $A$  is the acceleration constant. Using a method similar to the

method shown in FIG. 8, the parameters  $A$ ,  $S$ ,  $R$ , and  $T_R$  can be estimated by applying them to the actual data and refined by using the optimization method.

In FIG. 3, it was shown that the present invention employs three radar sensors 110, 112, and 114 to determine a three dimensional (3-D) velocity vector for the object 42. The speed/distance model for a single sensor used the function  $F(S, R, T_R)$ . The speed/distance function can be extended to a system that employs multiple sensors. For a system employing three sensors, the speed/distance function is defined as  $(s_{0t}, s_{1t}, s_{2t}) = F_t(S, R_0, T_{R_0}, R_1, T_{R_1}, R_2, T_{R_2})$  where  $s_{it}$  is the speed that the sensor  $i$  observes at time  $t$ ;  $S$  is the actual speed of the target;  $R_i$  is the minimum distance between the target and sensor  $i$  for all values time  $t$ ; and  $T_{R_i}$  is the time at which the target is at the minimum distance  $R$  from sensor  $i$ .